The Diamond Makers. Robert M. Hazen. Cambridge. 1999.

Although diamonds, the most exquisite of gems, have been known and coveted for thousands of years, surprisingly enough, their chemical nature became understood only about 200 years ago. Smithson Tennant astonished the world by proving that common charcoal and diamond had an identical constituent. All other gemstones – sapphire, emerald, ruby – are oxides of various sorts, while pearls are even more complex. In the book under review, the author Robert Hazen describes the fascinating story of the race to make artificial diamonds. Hazen is a research scientist with the Carnegie Institution and a leader in the scientific literacy movement, having authored a well-known book on superconductors. The race involved industrial giants such as General Electric (GE) of USA, De Beers of South Africa and ASEA of Sweden. Scientists, eccentric and controversial, who were on this trail are described with a touch of humour, with their catastrophic (literally!) failures and hard-won successes.

The story of *The Diamond Makers* is also a story of the study of material properties – physics and chemistry – at high pressures. Such pressures occur below the surface of the earth where diamonds nucleate. The pressure at the centre of the earth is at least a few million times that on its surface, which is approximately one bar.

How does one realize such megabars of pressure in laboratories? Serendipity has decreed that this is possible using diamonds to squeeze materials in what are known as Diamond Anvil Cells. Diamond is strong, transparent to light and X-rays, and so an ideal window to study transformations under pressure. It is well known that substances undergo interesting transitions at high pressures – insulators become metallic, metals become superconductors and so on. One of the real challenges is to study the behaviour of hydrogen at megabar pressures – does it become metallic and superconducting as some theorists have predicted? At these pressures, however, even diamond sometimes fractures – hence the chapter on 'Diamond breakers' by Hazen.

Hazen takes us on a voyage of the history of diamonds through the ages – one full of romance and intrigue concerning the fabled Orloff and Hope diamonds and the discovery of the Cullinan in South Africa, which was at first thrown out of the window because of its outrageous size – one and a half pounds! Among scientists, Newton wondered at its miraculous power of splitting white light and speculated that it could be 'an unctuous substance coagulated' – a solidified oil which would be combustible. Wrong on the first count, but right on the second! Lavoisier proved, by igniting a small piece and collecting the evolved gas, that diamond was mainly carbon, but it was Smithson Tennant who provided clinching evidence.

The synthesis of diamond intrigued H. G. Wells, but practical steps were taken by the Scottish chemist Hannay who employed explosive techniques. It was no surprise that his quest ended with 'exploding iron tubes and shattered furnaces'. The French Nobel Prize winner, Moissan, joined the fray and gave the concept of 'nucleation' but in the end, he was no more successful than was William Crookes. It was a hit-or-miss approach, with the gradual realization that temperatures of thousands of degrees as well as pressures of thousands of atmospheres were necessary to produce diamond. Some of these pioneers died convinced that they had succeeded, but they were usually deluded by the initial nucleating pieces of the gem that were recovered after the explosions.

Using X-rays W. H. and W. L. Bragg discovered the crystalline structure of diamond, which is distinct from the layered structure of graphite. Interestingly silicon, the material from which all IC chips are made, also has this 'diamond structure'. The way was now open to draw up a tentative phase diagram which could predict the conditions of temperature and pressure under which graphite and diamond are stable.

Enter Percy Bridgman at Harvard, the father of modern high-pressure physics! An innovator par excellence and inventor of the (Bridgman) high-pressure cell, there was no material that he could lay his hands on that he did not squeeze between his anvils. The synthesis of diamond posed a challenge he could not resist. Bridgman got up to 75,000 atmospheres at 700°C, but try as he might, his efforts at diamond synthesis proved futile.

The diamond story involved many charismatic characters such as George Kennedy of Harvard and UCLA, but none more so than Baltzar von Platen, who got the Swedish Electric giant ASEA to invest millions in a major laboratory stocked with cumbersome equipment, including a 14-ton press which was housed in a palace outside Stockholm. Starting with iron carbide and graphite, this team used thermite as an explosive and met with some success in 1953. However the work was carried out in complete secrecy and results were not published till after General Electric's success. All this effort was thus relegated to a footnote.

General Electric, the brainchild of Edison, took up the challenge in 'Project Superpressure'. As befits an industrial laboratory, it assembled a team of interdisciplinary scientists. They invested in a press weighing 55 tons, which was two stories tall. Through painstaking experiments and systematic improvements of equipment, the GE team succeeded in 1954. However, controversy dogged the first results of Herb Strong. Tracy Hall, with his belt apparatus, is now credited with being the first to *reproducibly* synthesize diamond. The estimated conditions were 100,000 atmospheres pressure at 1600°C maintained for 38 minutes. The GE team included names like Tracy Hall, Herb Strong and Francis Bundy, who became legends in high-pressure research.

What was the key to GE's success? It was to reach temperature and pressure conditions at which diamond was the stable form of carbon and simultaneously the metal catalyst used – iron, nickel, chromium, etc. – was in a liquid state. The liquid metal not only dissolved the carbon, but also catalysed crystal growth. The first complete phase diagram showing the occurrence of diamond, graphite and liquid carbon as a function of temperature and pressure, was a valuable outcome of this work.

GE's first public announcement in 1955 sent tremors through De Beers, the South African cartel that controlled the supply of natural diamonds used mainly for industrial purposes like cutting tools. The price of their stock dropped precipitously, while that of GE jumped overnight. Eager to capitalize on their success, GE carried out 100 runs to produce 23 carats of tiny, *black* synthetic crystals to be used as abrasives. De Beers had no fear of competition as far as gemstones were concerned! Far from becoming rich, the GE inventors Bundy, Hall, Strong and Wentorf, each received a princely $25 savings bond as bonus for their breakthrough. Tracy Hall, bitter that his key contributions were so little recognized, soon left GE for a university, where he was to make a mark with his unique tetrahedral anvil cell. Hazen suggests that with proper publicity and promotion by GE, the first synthesis of diamond was worth a Nobel Prize.

GE started a separate division for manufacture of industrial diamonds, reaching a capacity of 1500 pounds (3.5 million carats) by 1959, at $2 per carat. Through untiring effort, Strong and Wentorf learnt to make perfect crystals as large as one carat. However by Hazen's admission, these will hardly make a dent in the market for gems, as they take very long to grow and the giant presses are too expensive to run. De Beers was also finally successful in diamond synthesis, but lost their protracted patent suits against GE. Nevertheless they set up their own manufacturing plants in Ireland.

What of recent developments? Man can sometimes score over nature. Diamond is pure carbon, some trace impurities imparting characteristic colours. Carbon has an atomic mass of 12, but natural carbon contains a small percentage of the isotope with mass 13. It has now been possible to grow diamond crystals containing exclusively carbon 12 atoms. These are called isotopically pure (isopure) diamonds and have some unique properties. For example, their thermal conductivity is about 50% higher than that of natural diamond. It is not commonly known that diamond, while an excellent electrical insulator, is a better conductor of heat than copper. This is another striking property which has been exploited for heat sinks of sophisticated semiconductor devices such as lasers. These diamond crystals are of course not gems, but of the industrial variety.

Fine-grain diamond suitable for abrasives are now being prepared by explosive technique, but recently there has been an upsurge of interest in preparing diamond films by relatively low-cost techniques. It is known that plasmas contain ions and electrons with high energies, which is equivalent to high temperatures. The Russians led by Derjaguin, had been toying with such alternative plasma techniques using chemical vapour deposition from methane – common marsh gas. Their attempts met with success so that microcrystalline films could be prepared on a variety of substrates kept at high temperature. This technique still remains an incompletely understood art, but holds the promise of laying down semiconducting films for diamond devices which could be useful at high temperatures, but can never hope to replace silicon.

There is an Indian angle to this – one of the pioneer workers in high pressure synthesis has been Rustom Roy of Pennsylvania State University. His study of phase diagrams of silica and other minerals are classics in the literature, as mentioned by Hazen. It was he who alerted the US community to the Russian work on plasma deposition of diamond. Hazen however, misses out on C. V. Raman's pioneering studies on diamonds, which have become just as important as Braggs' X-ray diffraction. In fact, it is the Raman spectrum of films that is universally used as the signature to distinguish diamond from diamond-like or amorphous carbon. Also, strangely absent is any mention of the Kohinoor, about which an entire section could have been written. There is also no explicit discussion of the different types of diamond – Types I, IIa and IIb, nor what constitutes 'American diamond' – zirconium silicate. Notwithstanding these omissions, Hazen has written an enthralling book that reveals the human aspects underlying exploration and innovation in a fascinating field which is off the beaten track. It weaves stories of failure and success, intuition and doggedness, to give a flavour of what research at the frontiers is all about.

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Science and Technology Data Book-2000. DST, Ministry of Science and Technology, Govt of India, New Delhi. 83 pp. Price not mentioned.

While assessing the content and presentation of the book under review, it is useful to trace the need, relevance and compulsions leading to the preparations of such data books.

Over the past three decades, there has been a growing need in India for an information system and database on science and technology statistics, popularly called 'Science Statistics'. Science statistics is defined as a field of statistics dealing with the quantitative measurement of the volume and structure of scientific and technological activities of a given country. It provides a conceptual framework wherein information is organized with the aim of measuring, analysing and evaluating a set of variables relevant to science policy making. Policy makers, particularly those concerned about planning, implementation and management of science, besides science policy researchers, felt the need for comprehensive information not only on the use of input resources (mainly human and financial) and infrastructure available, but also on the output of such activities measured in terms of increased productivity and economic growth, new products and processes and their large-scale diffusion and impact on society, such as economic growth measured by increased value added and trade in technology-intensive products and growth in scientific activity by increased publication count and citation index. Such information could be useful for undertaking cost–benefit analysis and other economic studies as well as efficient programming, planning and budgeting, and to compare the national efforts with those of other countries.

With the growing awareness of these needs, a number of countries including India have started data collection on scientific and technological activities (STA) which cover Research and Experimental Development (R&D), Scientific and Technological Education and Training at broadly third level (STET), and Scientific and Technological Services (STS). Over time, the statistics on S&T has expanded by not only covering the human and financial resources deployed, but also covering data on education of S&T personnel, scientific services and S&T activities related to production, design, quality control, patents, foreign collaboration and so on.

A need was felt in India since independence, for establishing a database for resources input to and output from S&T activities, but it assumed seriousness since the beginning of the 1970s. In fact, since 1976 (when the author of this